SOME PHILOSOPHICAL ASPECTS OF PARTICLE PHYSICS

BSPS 1975

Cambridge 1978

History of Theoretical Developments in Particle Physics

1927 : Relativistic Quantum Field Theory

1947 : Renormalization
→ Feynman Diagrams

1958 : The Analytic S-Matrix
→ Bootstrap Hypothesis

1967 : Revival of Field Theories
— Unified Gauge theories

Field Quantization

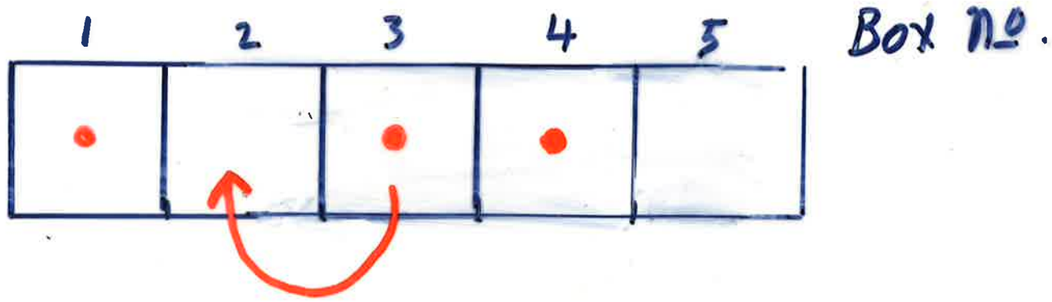
Classical field $\xrightarrow{\text{field quantization}}$ Quantized Field.

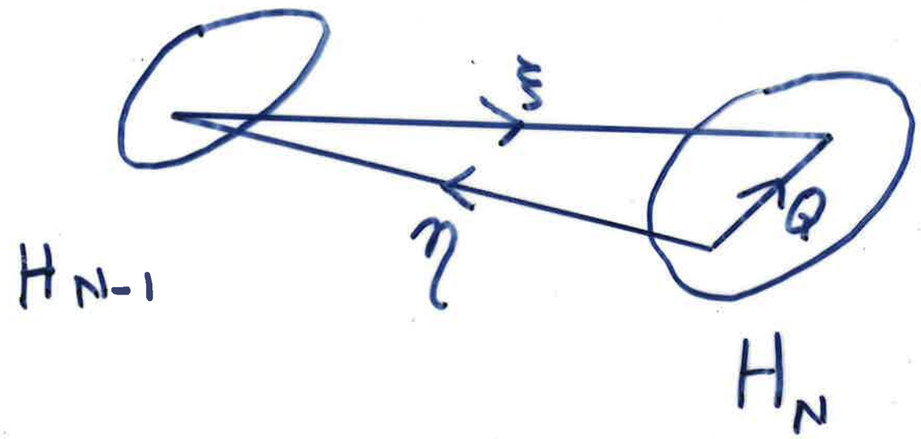
Second Quantization

N classical Particles $\xrightarrow{1^{st}\text{ quantization}}$ N-Particle Schrödinger Eq.

$\xrightarrow{2^{nd}\text{ quantization}}$ Quantized Field

Second Quantization

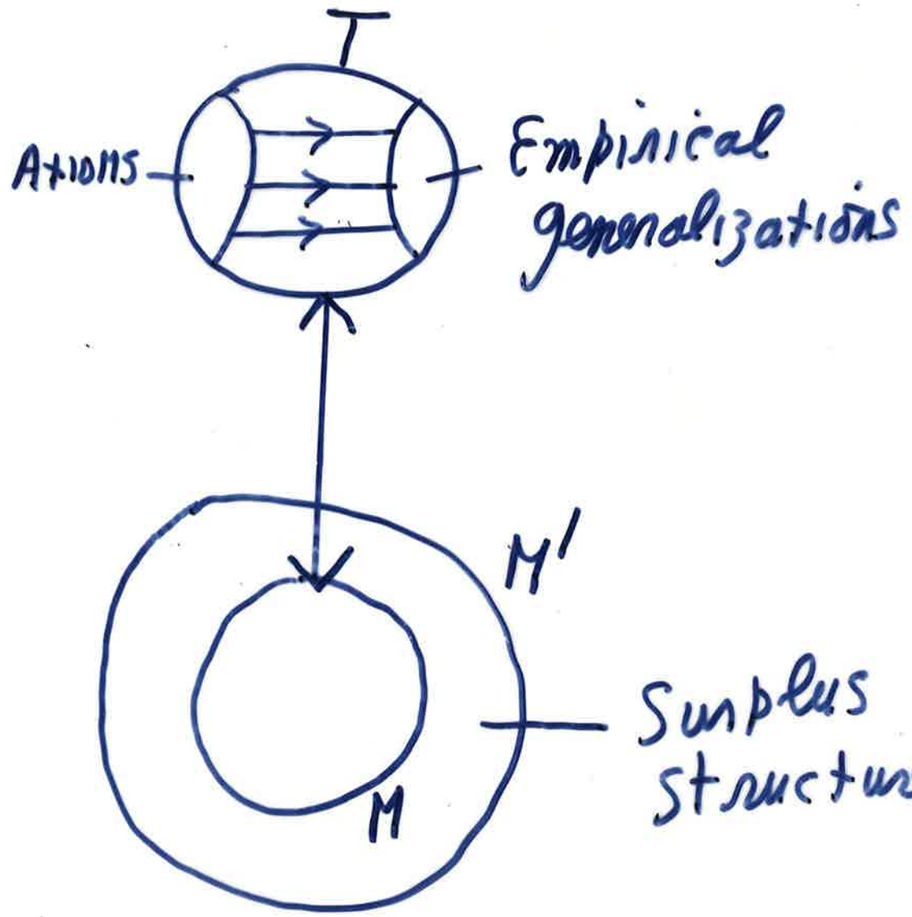




we "factorize" $Q = \xi\eta$

what about $Q' = \xi + \eta$?

Surplus Structure



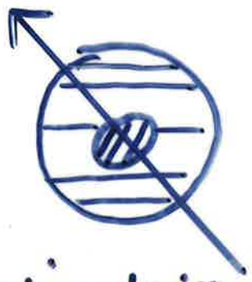
Reformulation & "Stretching"

Classical N-Particle Theory

Metaphysical Paradigm Shift →

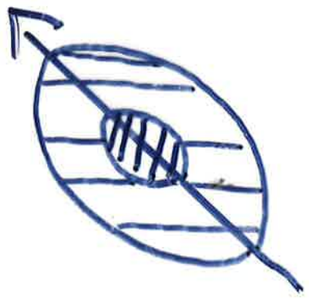
N-Particle Schrödinger Eq.

Directional Shift →



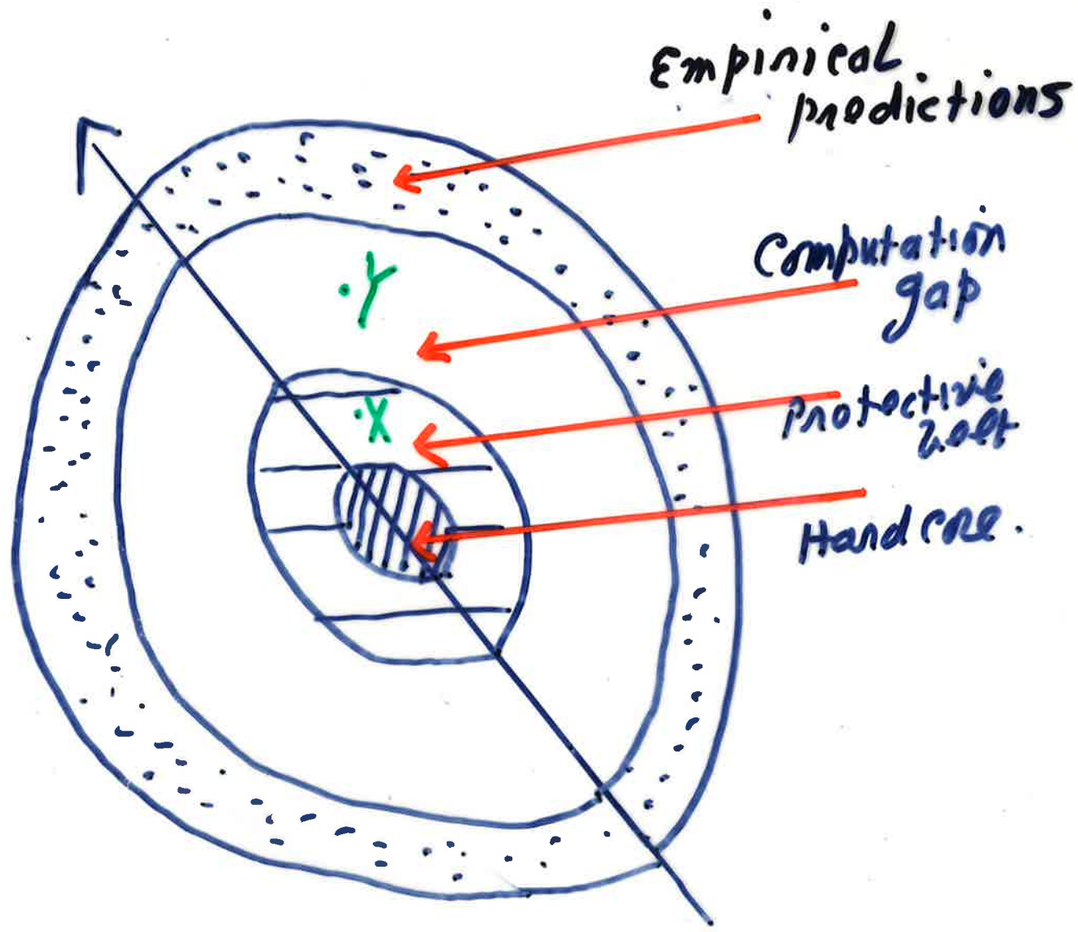
2nd quantization formulation with fixed no of particles

"stretching" of theory →

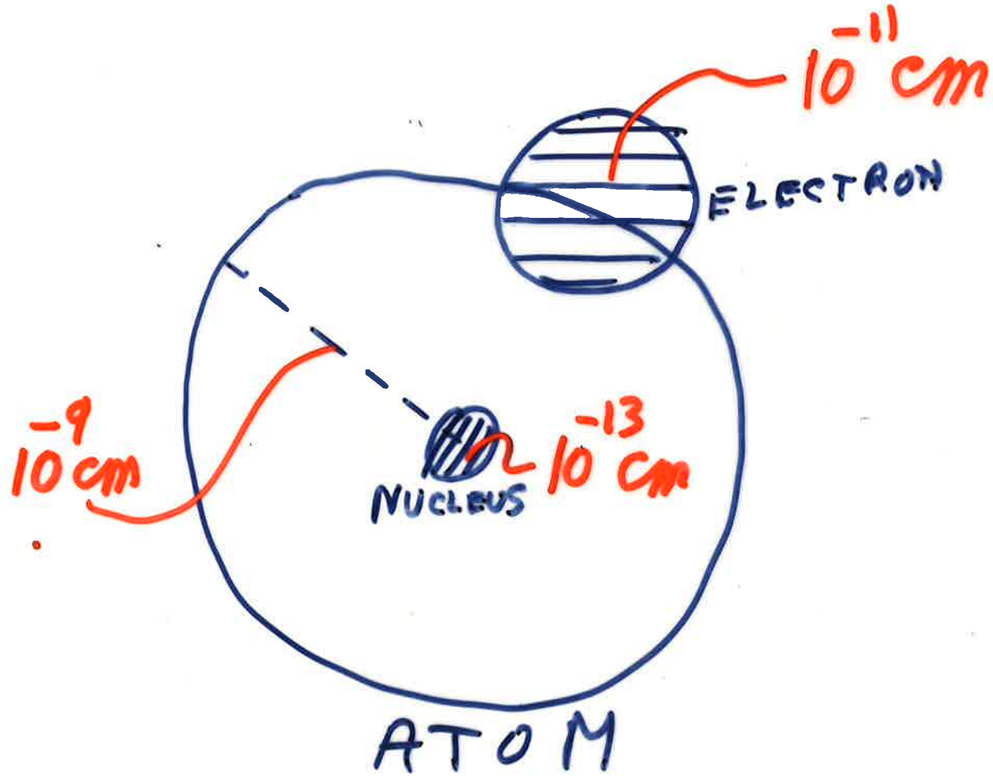


RQFT with Variable no of particles

The Computation Gap



The Smeared Electron



Classical Renormalization

Eq. of motion for an electron of radius r_0 is :—

$$m \ddot{\underset{\sim}{r}} = \underset{\sim}{K}^{(0)} + \underset{\sim}{K}^{(1)} + \cdots$$

where $\underset{\sim}{K}^{(0)} = -\beta \cdot \frac{e^2}{r_0 c^2} \ddot{\underset{\sim}{r}}$, $\beta \sim 1$

$$\underset{\sim}{K}^{(1)} = 2/3 \; e^2/c^3 \cdot \dddot{\underset{\sim}{r}} \quad \text{etc}$$

We rewrite this as

$$m' \ddot{\underset{\sim}{r}} = \underset{\sim}{K}^{(1)} + O(r_0)$$

where $m' = m + \beta \cdot \frac{e^2}{r_0 c^2}$

We identify m' with experimental mass and <u>then</u> let $r_0 \to 0$.

The Subtraction of Infinite Quantities

Consider $I = \int_{-a}^{b} x\,dx = \frac{1}{2}(b^2 - a^2)$

$\lim_{a,b\to\infty} I$ is quite ambiguous

e.g. with $b = a$, $I \to 0$

$a = b - 1/b$, $I \to 1$

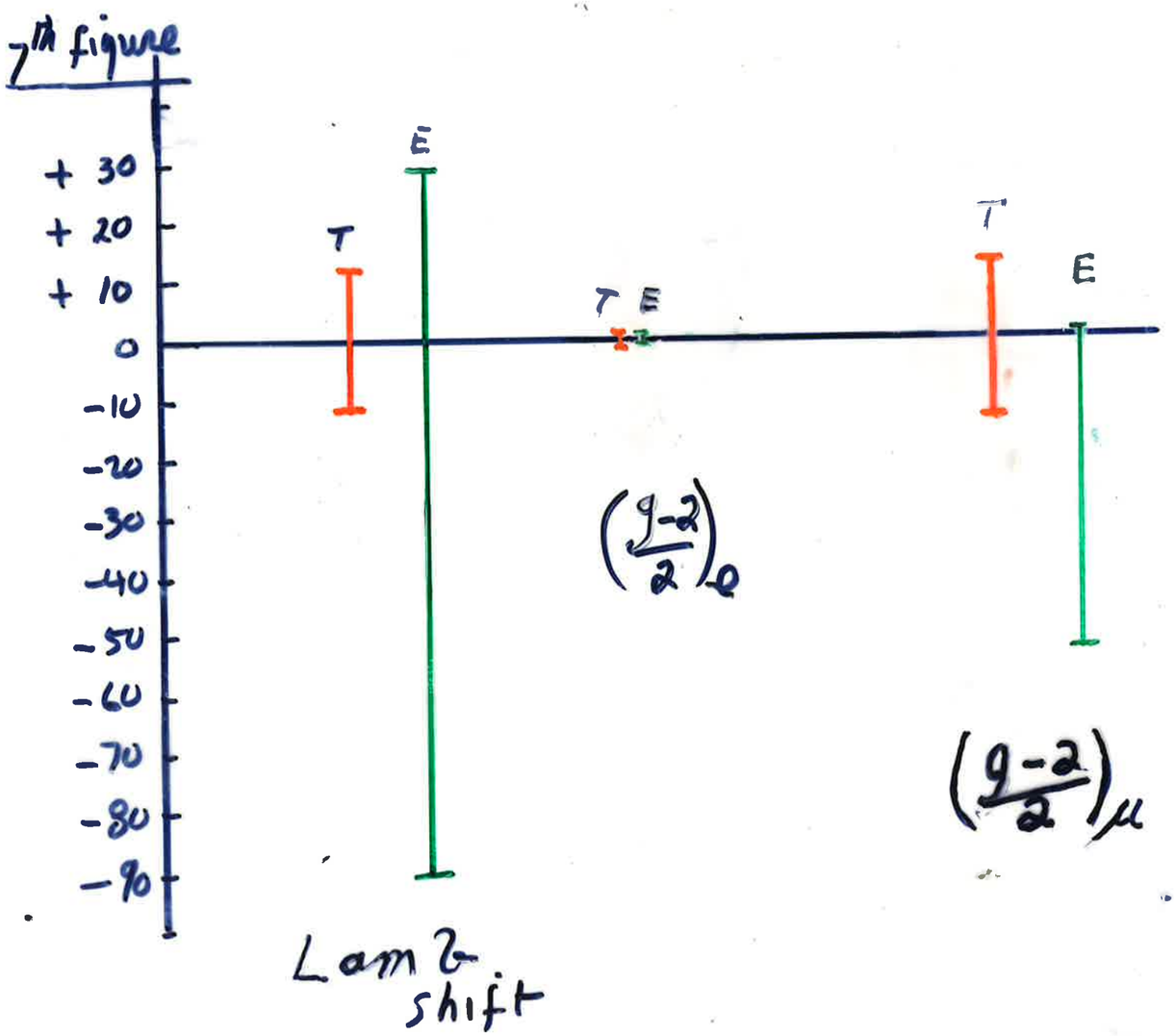
and so on.

But if we consider symmetry under reflection $x \to -x$, then if we specify an invariant range of integration we obtain the unambiguous value $I = 0$

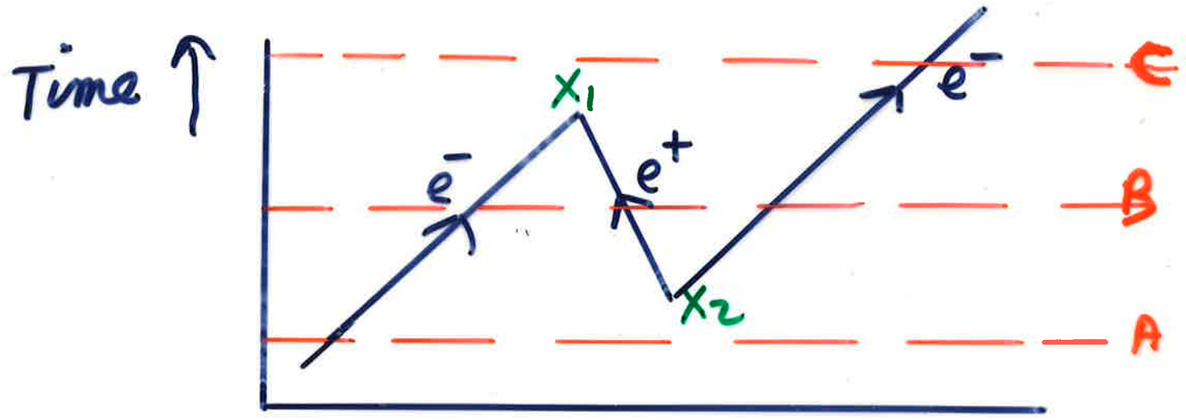
cf. $I = \int_{-a}^{b} x e^{-x^2} dx = \frac{1}{2}\left[e^{-a^2} - e^{-b^2}\right] \to 0$.

as $a, b \to \infty$ in any manner.

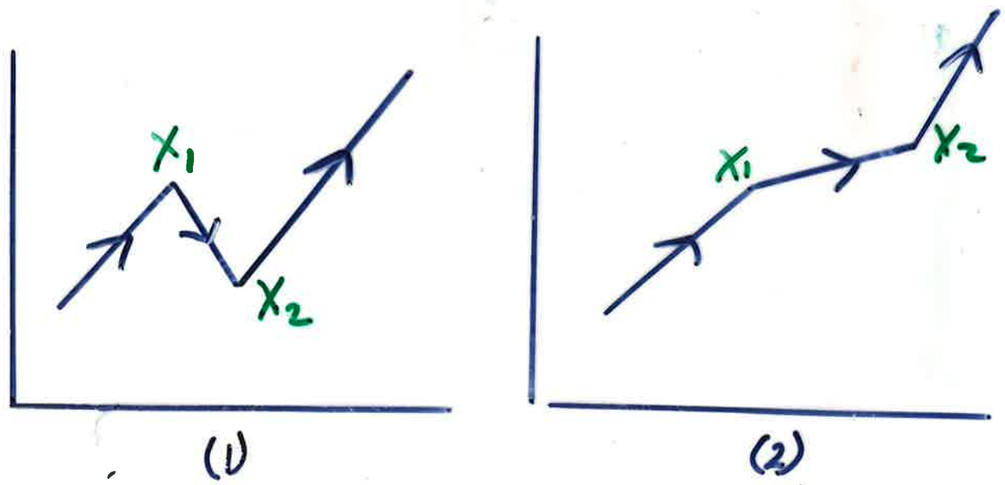
The Lamb Shift in Hydrogen and the anomalous magnetic moment of the electron and the Muon.



Feynman Diagrams



Hamiltonian Picture



Feynman Picture

The Four Basic Interactions

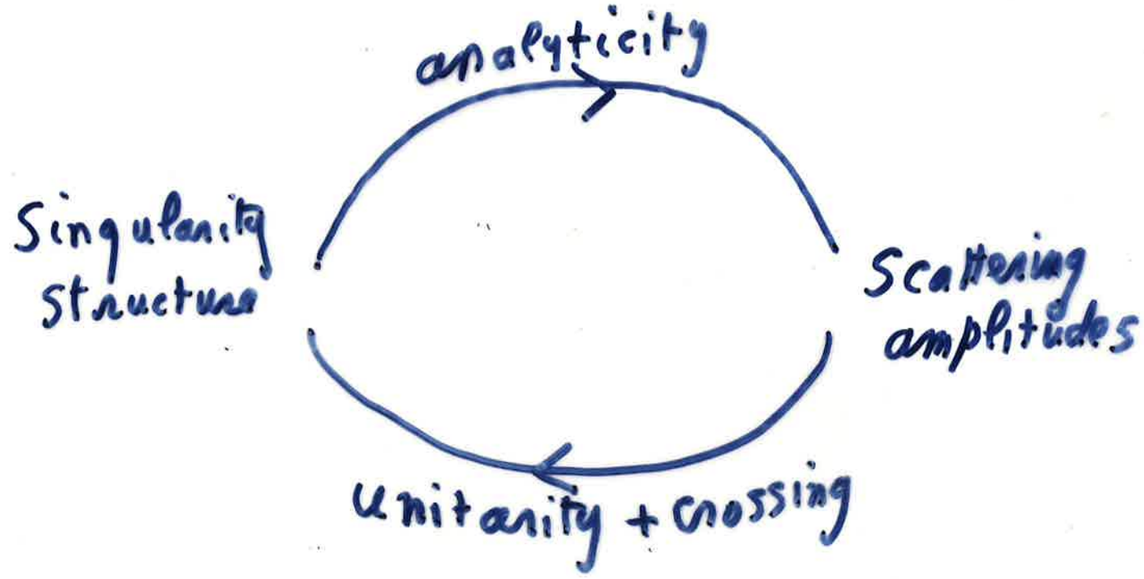
	Strength	Range
strong	1	10^{-13} cm
Electromagnetic	10^{-2}	∞
Weak	10^{-13}	10^{-15} cm (?)
Gravitational	10^{-39}	∞

TABLE OF THE PARTICLES

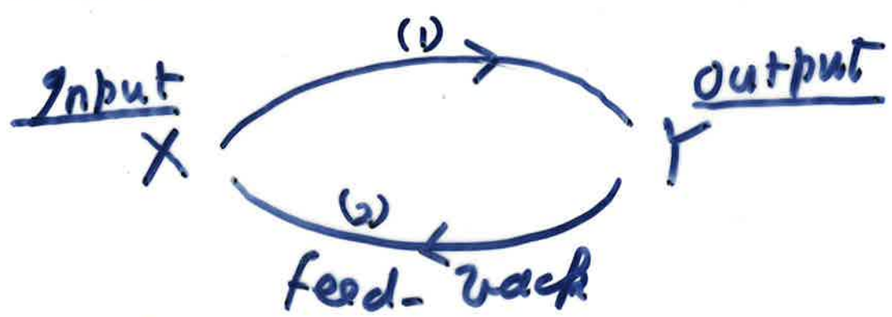
BOSONS		FERMIONS	
HADRONS		HADRONS	
MESONS	150 π (pion) 500 K (Kaon) 550 η + resonances 750 ρ 800 ω ⋮ 3,100 J/ψ	BARYONS	nucleons {proton, neutron} 950 Hyperons {Δ 1100; Σ 1200; Ξ 1300; Ξ 1650} + resonances Δ(1232) ⋮
	0 photon 0 graviton (?) 20,000 W- particle (?)	LEPTONS	{neutrinos: ν_e 0, ν_μ 0; electron 1/2; muon 100}
GLUONS (?)		QUARKS (?)	

Rest energies in MeV rounded to nearest 50 MeV.

The Analytic S-Matrix



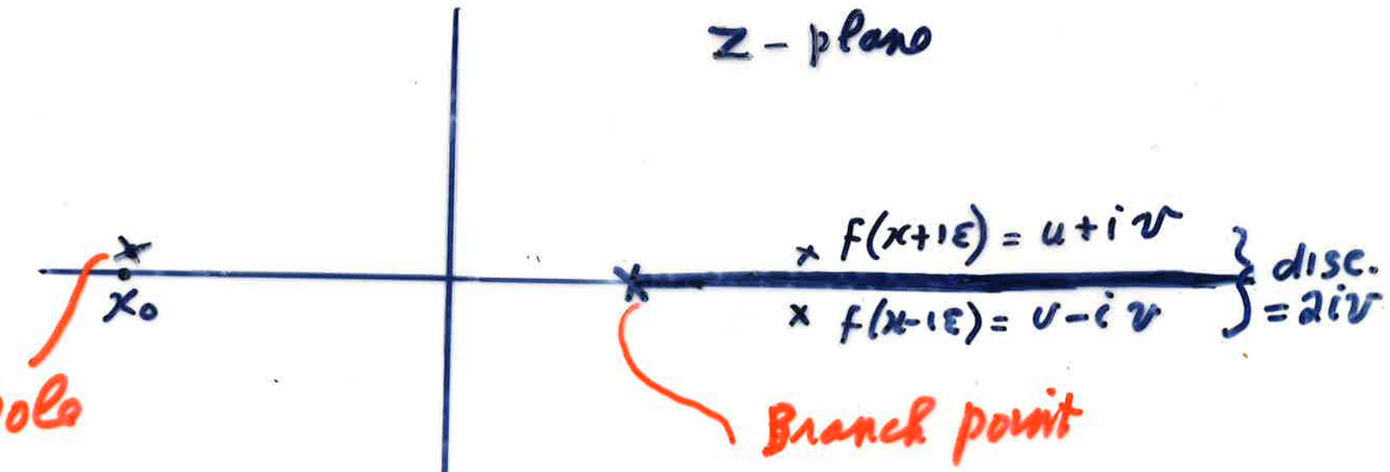
Compare with :—



Ex (1) $Y = X$
(2) $X = Y^2$
} Soln is $Y = 0$ or 1

To remove ambiguity we need an extra principle e.g. Soln must be symmetric under reflection in the origin $\Rightarrow Y = 0$

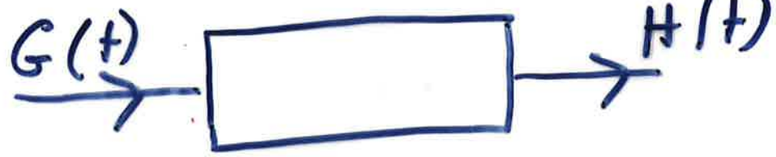
Singularities from Unitarity



$$\frac{1}{x-i\varepsilon-x_0} = P\left(\frac{1}{x-x_0}\right) + i\pi\,\delta(x-x_0)$$

We assume $f(z^*) = f^*(z)$ so $f(z)$ is real on real axis before the branch point.

Analyticity & Causality



Linear causal response:

$$H(t) = \int_{-\infty}^{\infty} L(t-t')\, G(t')\, dt'$$

with $L(\tau) = 0, \ \tau < 0$

Scattering amplitude is related to the Fourier transform $\hat{L}(\omega) = \int_0^{\infty} L(\tau) e^{i\omega\tau} d\tau$

this is analytic function of ω in upper half plane.

whence, from Cauchy's Theorem we obtain the Kramers-Kronig relation

$$\mathrm{Re}\,\hat{L}(\omega) = \frac{2}{\pi} P \int_0^{\infty} \frac{\mathrm{Im}\,\hat{L}(\omega')\, \omega'\, d\omega'}{\omega'^2 - \omega^2}$$

(using crossing property $\mathrm{Im}\,\hat{L}(-\omega) = -\mathrm{Im}\,\hat{L}(\omega)$)

The Chew-Mandelstam Heuristic Strategem

original theory: T + approximation: $A \rightarrow T_1 \rightarrow P$ (explains C)

T_1: approximate theory

P: property of the model

$\rightarrow T'(P)$

new theory with P incorporated as an axiom.

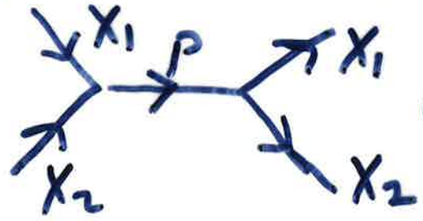
Bootstraps

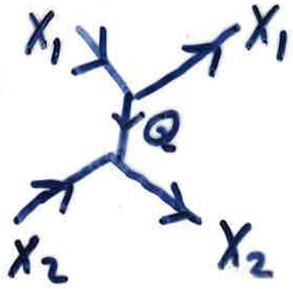
(1) $P = \pi\pi(P)$

(2) $N = N\pi(N)$
$\pi = N N(\pi)$

(3) $N = N\pi(N^*)$
$N^* = N\pi(N)$

In general $\{P_1 P_2 \cdots\} = X_1 X_2 \cdots (Q_1 Q_2 \cdots)$

So 

is derived from 

and $\{P\}$, $\{X\}$ and $\{Q\}$ are all same set.

The Bootstrap

$$\{P_1 P_2 \cdots\} = X_1 X_2 \cdots (Q_1 Q_2 \cdots)$$

composites — constituents — "exchange particles"

$\{P\}$, $\{X\}$, $\{Q\}$ are all the same set

The Ultimate Nature of Matter

1. The Bootstrap Picture

$$X_1 = \begin{cases} X_1 \\ X_a + X_2 \\ X_a + X_2 + X_c \\ \vdots \end{cases}$$

$$X_2 = \begin{cases} X_2 \\ X_a + X_2 \\ \vdots \end{cases}$$

2. Thalean Fundamentalism

"Solve" the bootstrap as

$$X_1 = Q_1 + Q_2 + Q_3 + \cdots$$
$$X_2 = Q_1 + Q_2 + Q_3 + \cdots$$
$$\vdots$$

3. Anaximandrian Fundamentalism

$$X_1 = X_1(F)$$
$$X_2 = X_2(F)$$
$$\vdots$$